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HIGH Cr MARTENSITE STAINLESS STEEL PIPE FOR LINE PIPE WITH
EXCELLENT CORROSION RESISTANCE AND WELD-ABILITY AND MANUFACTURING
METHOD THEREOF

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[Scope of Patent Claims]

[Claim 1] A high Cr martensite stainless steel pipe for line pipe with excellent corrosion resistance and weld-ability, characterized by having a composition containing the following in mass %:

C: 0.02 % or less Si: 1.0 % or less
Mn: 0.2-3.0 % P: 0.05 % or less
S: 0.005 % or less Cr: 10-14 %
Ni: 0.2-0.7 % Mo: 0.2-3.0 %
Al: 0.1 % or less N: 0.07 % or less

as well as Fe and inevitable impurities as the remainder and having a texture containing martensite phase as the main phase and an austenite phase of 5 % or more in area rate.

[Claim 2] The high Cr martensite stainless steel pipe for line pipe described in Claim 1, characterized by also containing one or several kinds selected from Ti: 0.15 % or less, Nb: 0.2 % or less, Zr: 0.15 % or less, V: 0.2 % or less, Ta: 0.15 % or less in mass % in addition to the aforementioned composition.

[Claim 3] The high Cr martensite stainless steel pipe for line pipe described in Claim 1 or 2, characterized by also containing 0.006 % or less of Ca in mass % in addition to the aforementioned composition.

[Claim 4] A method for manufacturing high Cr martensite stainless steel pipe for line pipe with excellent corrosion resistance and weld-ability, characterized by the following facts: a steel raw material having a composition containing the following in mass %:

C: 0.02 % or less Si: 1.0 % or less

Mn: 0.2-3.0 % P: 0.05 % or less

S: 0.005 % or less Cr: 10-14 %

Ni: 0.2-0.7 % Mo: 0.2-3.0 %

Al: 0.1 % or less N: 0.07 % or less

is used to manufacture steel pipe with prescribed dimensions; then, this steel pipe is heated to a phase transition point A_{c3} or higher, followed by cooling to form a quenched texture; then, the steel pipe is tempered at a temperature of 520°C or higher to deposit the austenite phase to obtain a texture containing martensite phase as the main phase and an austenite phase of 5 % or more in area rate.

[Claim 5] The method for manufacturing high Cr martensite stainless steel pipe for line pipe described in Claim 4, characterized by the fact that the steel pipe contains one or several kinds selected from Ti: 0.15 % or less, Nb: 0.2 % or less, Zr: 0.15 % or less, V: 0.2 % or less, Ta: 0.15 % or less in mass % in addition to the aforementioned composition.

[Claim 6] The method for manufacturing high Cr martensite stainless steel pipe for line pipe described in Claim 4 or 5,

characterized by the fact that the steel pipe also contains 0.006 % or less of Ca in mass % in addition to the aforementioned composition.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention pertains to a high Cr martensite stainless steel pipe that can be suitably used as line pipe for transporting petroleum/natural gas. In particular, the present invention pertains to improvement of corrosion resistance and weld-ability.

[0002]

[Prior Art] In recent years, because of the price spike of the crude oil, and the prediction that the petroleum/natural gas resources will run out in near future, deep oil fields and highly corrosive oil fields/gas fields that have never been considered before are being well exploited. Almost all of these oil fields/gas fields are located deeply either in the sea or very cold areas or other so-called remote areas and have severe corrosive environments containing carbon dioxide CO₂, chlorine ions Cl⁻, and the like.

[0003] Carbon steel will be badly corroded if it is used as the material for oil well pipes or line pipes in such highly

corrosive wet carbon dioxide environment. Therefore, inhibitor has been added into the exploited crude oil/gas as an anti-corrosion means for oil well pipes or line pipes. However, the addition of the inhibitor leads to increase of the cost because the inhibitor is expensive. Also, the effect of adding inhibitor is unsatisfactory at high temperature. Therefore, recently, there has been a tendency of using corrosion resistant material as the material for oil well pipes or line pipes instead of adding inhibitor.

[0004] Martensite stainless steel containing 13 % of Cr has been widely used as said corrosion resistant material for oil well pipes. Recently, in order to adapt to the corrosive environment containing a small amount of hydrogen sulfide, for example, Japanese Kokai Patent Application No. Sho 60[1985]-174859 discloses an oil well pipe with improved SSC resistance by adding Ni, Mo, or the like into the martensite stainless steel containing 13 % of Cr. The oil well pipe disclosed in Japanese Kokai Patent Application No. Sho 60[1985]-174859, however, gives no consideration to the weld-ability at all. Weld cracking would occur when welding is performed without pre-heating and post-heating.

[0005] On the other hand, 12 % Cr martensite stainless steel pipe containing less C is regulated according to API standards as a material for line pipe. However, since this type of steel pipe

has low weld-ability, it is necessary to perform pre-heating and post-heating during welding. As a result, the welding construction efficiency becomes low, and the cost is increased. In addition, the tenacity of the welded part is low. There has been almost no record of using this material. Two-phase stainless steel with excellent weld-ability and corrosion resistance has been used instead of the aforementioned material as material for line pipe. However, the two-phase stainless steel contains large amount of alloys and displays excessive performance depending on the place of use. The cost effectiveness may be undesired.

[0006] Also, since high-temperature gas/fluid flows in line pipe, it is necessary to keep the strength (high-temperature strength) during use at a high level. In order to increase the strength of the line pipe during use (high-temperature strength), the normal-temperature strength of the line pipe is usually increased to increase its high-temperature strength, or the thickness of the line pipe is usually increased. However, when the normal-temperature strength of the line pipe is increased, the weld-ability may deteriorate.

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When the thickness of the line pipe is increased, the material cost will be increased.

[0007]

[Problems to be Solved by the Invention]

The objective of the present invention is to solve the aforementioned problems by providing a high Cr martensite stainless steel pipe with excellent corrosion resistance and weld-ability, which has sufficiently high full surface corrosion resistance and hole corrosion resistance in a corrosive environment containing carbon dioxide and has excellent SSC resistance in an environment containing hydrogen sulfide and has excellent tenacity in the heat-affected zone, as well as the manufacturing method of this steel pipe.

[0008]

[Means for Solving the Problem] In order to realize the aforementioned objective, the present inventors have conducted extensive research on various factors affecting the corrosion resistance, and weld cracking in corrosive environment containing carbon dioxide, as well as the tenacity of the heat-affected zone of the high Cr martensite stainless steel pipe. As a result of this study, it was found that martensite stainless steel pipe with excellent weld-ability and corrosion resistance in a corrosive environment mainly containing carbon dioxide could be achieved by combining factors (1)-(3), that is, (1) containing appropriate amounts of C, N, (2) containing Ni, Mo, and (3) forming a texture containing 5 % or more of austenite. In particular, the steel pipe obtained this way also had excellent SSC resistance and tenacity of the heat-affected zone.

[0009] The present invention is achieved by conducting further studies based on the aforementioned knowledge. The first invention discloses a high Cr martensite stainless steel pipe for a line pipe with excellent corrosion resistance and weld-ability, characterized by having a composition containing, in mass %, C: 0.02 % or less, Si: 1.0 % less, Mn: 0.2-3.0 %, P: 0.05 % or less, S: 0.005 % or less, Cr: 10-14 %, Ni: 0.2-0.7 %, Mo: 0.2-3.0 %, Al: 0.1 % or less, N: 0.07 % or less as well as Fe and inevitable impurities as the remainder and having a texture containing a martensite phase as the main phase, and an austenite phase of 5 % or more in area rate. Also, in the first invention, preferably, the steel pipe also contains one or several kinds selected from Ti: 0.15 % or less, Nb: 0.2 % or less, Zr: 0.15 % or less, V: 0.2 % or less, Ta: 0.15 % or less in mass % in addition to the aforementioned composition. In addition, in the first invention, preferably, the steel pipe also contains 0.006 % or less of Ca in mass % in addition to the aforementioned composition.

[0010] The second invention discloses a method for manufacturing high Cr martensite stainless steel pipe for line pipe with excellent corrosion resistance and weld-ability, characterized by the following facts: a steel raw material having a composition containing, in mass %, C: 0.02 % or less, Si: 1.0 % less, Mn: 0.2-3.0 %, P: 0.05 % or less, S: 0.005 % or less, Cr: 10-14 %, Ni: 0.2-0.7 %, Mo: 0.2-3.0 %, Al: 0.1 % or less, N: 0.07 % or less,

and preferably, Fe and inevitable impurities as the remainder is used to manufacture steel pipe with prescribed dimensions; then, this steel pipe is heated to a phase transition point Ac_3 or higher, followed by cooling to form a quenched texture; then, the steel pipe is tempered at a temperature of $520^{\circ}C$ or higher to deposit the austenite phase to obtain a texture containing martensite phase as the main phase and an austenite phase of 5 % or more in area rate. Also, in the second invention, preferably, the steel pipe also contains Ca: 0.0006 % in mass % in addition to the aforementioned composition.

[0011]

[Embodiment of the Invention]

First, the reasons of limiting the composition of the steel pipe in the present invention will be explained. In the following, mass % is simply referred to as %.

C: 0.02 or less

C can increase the strength of the base material. It, however, can also increase the hardness of the heat-affected zone to increase the vulnerability to weld cracking and lower the tenacity of the heat-affected zone. In the present invention, it is desired to lower its content as much as possible. In addition, the content of C is also desired to be low in order to improve the hole corrosion resistance in a corrosive environment containing carbon dioxide. In the present invention, in order to

make it possible to perform welding without preheating, the content of C should be 0.02 % or less, preferably, 0.01 % or less.

[0012] Si: 1.0 % or less

Si can act as a deoxidation agent and can also improve the strength. In order to display this effect, its content is desired to be 0.1 % or less. However, Si is a ferrite generating element. If its content is too high, ferrite will be generated to deteriorate the tenacity of the base material and the heat-affected zone. Therefore, the content of Si is limited to 1.0 % or less, preferably, in the range of 0.1-0.5 %.

[0013] Mn: 0.2-3.0 %

Mn can act as a deoxidation agent and can also improve the strength. Also, Mn is an austenite generating element that can restrain generation of ferrite to improve the tenacity of the base material and the heat-affected zone. Its effect can be recognized when the content is 0.2 % or more. However, when the content exceeds 3.0 %, the effect will be saturated, and no better effect is expected along with increase of the content. Therefore, the Mn content is limited to the range of 0.2-3.0 %, preferably, in the range of 0.5-2.0 %.

[0014] P: 0.05 % or less

Although P can improve strength, it will deteriorate stretch-ability and tenacity and degrade the corrosion resistance. In particular, it is segregated on the particle boundary to

deteriorate the strength of the particle boundary and adversely affect the SSC resistance. Therefore, the content of P should be as low as possible. However, an extremely low content will lead to increase of the manufacturing cost. Therefore, in the present invention, its content is limited to 0.05 % or less, which is possible to realize in the industrial field at a relatively low cost and will not cause serious deterioration of the tenacity and corrosion resistance. Preferably, its content is 0.03 % or less.

[0015] S: 0.005 % or less

S forms MnS or other sulfide-based medium, which would

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significantly deteriorate the ability to process heat. Its content should be as low as possible in order to improve the productivity. However, an extremely low content will lead to increase of the manufacturing cost. If the content of S is reduced to 0.005 % or less, the manufacture by normal process becomes possible. Therefore, in the present invention, the content of S is limited to 0.005 % or less, preferably, 0.003 % or less.

[0016] Cr: 10-14 %

Cr can form martensite texture to increase the strength and can form a protective film to improve the hole corrosion resistance and other corrosion resistance in corrosive environment containing carbon dioxide. In order to realize this

effect, the content of Cr must be 10 % or more. On the other hand, if the content exceeds 14 %, there is a strong tendency of generating ferrite. In order to stabilize and guarantee the martensite texture, it is necessary to contain a large amount of austenite generating element. As a result, the cost is increased. Therefore, in the present invention, the Cr content is limited to the range of 10-14 %.

[0017] Ni: 0.2-7.0 %

Ni is an austenite generating element. It can increase the strength and tenacity and alleviate the strength decrease and tenacity decrease caused by reduced C, N. Ni can also strengthen the protective film to improve the hole corrosion resistance and other corrosion resistance in corrosive environment containing carbon dioxide. In addition, Ni can restrain generation of δ -ferrite at high temperature to improve the ability to process heat of Mo-containing steel. In order to realize this effect, the content must be 0.2 % or more. However, a content of 7.0 % or more will lead to a poor cost effectiveness since Ni is expensive. Therefore, in the present invention, the Ni content is limited to 0.2-7.0 %, preferably, 0.5-5.5 %.

[0018] Mo: 0.2-3.0 %

Mo is an element used to improve the quenching property and increase the strength. It can also improve the SSC resistance. In order obtain this effect; the content must be 0.2 % or more.

However, if the content exceeds 3.0 %, ferrite tends to generate to lower the strength and tenacity and deteriorate the SSC resistance improvement effect. Therefore, the content of Mo is limited to 0.2-3.0 %, preferably, 0.5-2.5 %.

[0019] Al: 0.1 % or less

Al can act as a deoxidation agent. However, if its content exceeds 0.1 %, the tenacity will deteriorate. Therefore, in the present invention, the Al content is limited to 0.1 % or less, preferably, 0.05 % or less.

N: 0.07 % or less

Like C, N can be dissolved in steel to increase the strength of the base material. It, however, can also increase the hardness of the heat-affected zone to increase the vulnerability to welding cut and lower the tenacity of the heat-affected zone. Therefore, in the present invention, its content should be as low as possible. Since a content up to 0.07 % is allowed from the point of view of weld cracking, in the present invention, the N content is limited to 0.07 % or less, preferably, 0.03 % or less.

[0020] One or several kinds selected from Ti: 0.15 % or less, Nb: 0.2 % or less, Zr: 0.15 % or less, V: 0.2 % or less, Ta: 0.15 % or less

Ti, Nb, Zr, V, Ta can all form carbon nitrides to improve the strength and tenacity of the base material and the tenacity of the heat-affected zone. If necessary, the steel pipe may

selectively contain these elements. Also, when the Cr carbide is replaced by the carbides of Ti, Nb, Zr, V, Ta, the effective amount of Cr with respect to the hole corrosion resistance can be increased to improve the hole corrosion resistance. If the contents of these elements exceed Ti: 0.15 %, Nb: 0.2 %, Zr: 0.15 %, V: 0.2 %, Ta: 0.15 %, the vulnerability to weld cracking becomes higher to increase the danger of occurrence of weld cracking, and the tenacity of the base material and the heat-affected zone will deteriorate. Therefore, preferably, the aforementioned values are used as the respective upper limits of these elements. More preferably, Ti: 0.01-0.1 %, Nb: 0.01-0.1 %, Zr: 0.01-0.1 %, V: 0.01-0.1 %, Ta: 0.01-0.1 %.

[0021] Ca: 0.006 % or less

Ca can form sulfide CaS to restrain generation of MnS that is easy to dissolve so that the corrosion resistance can be improved. However, a high content will lead to generation of cluster-shaped medium to lower the tenacity of the base material. Therefore, it is preferred to limit the content of Ca to 0.006 % or less.

[0022] Fe and inevitable impurities as remainder.

The remainder besides the aforementioned components is composed of Fe and inevitable impurities. As an inevitable impurity, O: 0.01 % or less is allowed. Also, the texture of the steel pipe of the present invention contains the martensite phase

as the main phase and an austenite phase of 5 % or more in area rate. The main phase mentioned in the present invention refers to the phase occupying 50 % or more of area rate. When 5 % or more of austenite is contained in martensite as the main phase, the deposited Cr, Mo, and the like can be reduced to improve the corrosion resistance, and the strength of the steel pipe can be lowered [sic?] by short-period heat treatment. On the other hand, if the austenite phase is less than 5 %, since the amount of the deposited Cr, Mo is increased, the corrosion resistance will deteriorate. From the point of view of corrosion resistance, the more the austenite phase, the better. However, if the amount exceeds 35 %, it is difficult to obtain a prescribed strength. Therefore, preferably, the amount of the austenite phase is in the range of 5-35 %.

[0023] The texture of the steel pipe of the present invention contains the martensite phase as the main phase and austenite as described above and also contains 3 % or less (area rate) of deposited substances. In addition to the aforementioned phases, the steel pipe may also contain 3 % (area rate) or less of δ -ferrite phase without any problem. In the following, the method for manufacturing the high Cr martensite stainless steel pipe for line pipe disclosed in the present invention will be explained.

[0024] First, molten steel with the aforementioned composition is smelted by the conventional smelting method using converter or

electric furnace. It is preferred to manufacture billet or other steel pipe raw material by means of continuous casting method or slab rolling. It is preferred to manufacture seamless steel pipes with prescribed dimensions from the aforementioned steel pipe raw material by following the normal tubing process, that is, heating, piercing by Mannesmann piercer, and hot rolling by plug mill, mandrel mill or other tilt rolling type mill.

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The steel pipe in the present invention is not limited to seamless steel pipe but can also use electric resistance welded steel pipe, UOE steel pipe, spiral steel pipe, or other welded steel pipe.

[0025] For example, it is preferred to manufacture electric resistance welded steel pipes with prescribed dimensions by processing the steel pipe raw material with the aforementioned composition into steel belt by means of hot rolling, followed by the normal tubing process, that is, molding - welding - correction steps. It is preferred to manufacture UOE steel pipes or spiral steel pipes with prescribed dimensions by following the normal UOE steel pipe manufacturing process or spiral steel pipe manufacturing process.

[0026] A steel pipe with prescribed dimensions having the aforementioned composition and manufactured by the aforementioned normal tubing process is heated to Ac3 phase transition point or

a higher temperature, followed by cooling at a cooling speed equal to or faster than air cooling to form a quenched texture. IF the heating temperature of the steel pipe is lower than A_{c3} phase transition temperature, the heating temperature is too low to obtain a complete austenite texture, and the texture is not fully quenched. In this case, the fully quenched texture refers to a texture having quenched martensite of 95 % or more in area rate. On the other hand, if the temperature exceeds 1050°C , coarse austenite particles will be formed to deteriorate the tenacity. Therefore, it is preferred to keep the upper limit of the heating temperature to 1050°C .

[0027] Also, after heated, the steel pipe is cooled off to room temperature at a quench cooling speed equal to or faster than air cooling. The cooling method can be air cooling, mist cooling, or water cooling. After quenched, the steel pipe is tempered at a temperature of 520°C or higher. It is preferred to perform tempering under such conditions (temperature, time) that 5 % or more of austenite phase is generated. If the tempering temperature is lower than 520°C , in order to generate 5 % or more of austenite phase, it is necessary to perform tempering over long term. This will adversely affect the productivity. Therefore, the tempering temperature should be 520°C or higher, preferably, equal to or lower than the A_{c1} phase transition point.

More preferably, the tempering temperature is in the range of 600-650°C.

[0028]

[Application Examples] Steel having the composition shown in Table 1 was smelted in a converter, followed by a vacuum degassing treatment for refining. Then, the continuous casting method was used to manufacture steel pipe raw materials (billets). The steel pipe raw materials were heated, followed by tubing performed by Mannesmann-mandrel drill to obtain seamless steel pipes with outer diameter 273 mm x thickness 12.7 mm. Then, a heat treatment (quenching - tempering) was performed under the conditions shown in Table 2 to the steel pipes to obtain steel pipes of X80 grade.

[0029]

Test pieces were sampled from these steel pipes. Texture examination, tension test, impact test, and corrosion test were performed to evaluate the strength, tenacity, and corrosion resistance. Also, test pieces were sampled when the steel pipes were in the quenched state to evaluate the quenched texture.

(1) Texture Examination

On the cross section perpendicular to the length direction of each steel pipe, the picture of the texture was taken by using an optical microscope or a scanning electronic microscope. An image analytical device was used to measure the area rate of each

phase. Also, the austenite phase (γ) amount in the texture was calculated from the ratio between the diffraction intensity of γ from (220) and the diffraction intensity of α from (211) by using the X-ray diffraction method.

(2) Tension Test

A rod-shaped test piece with 6 mm ϕ was sampled from the length direction of each steel pipe, and the tension test was performed to measure the yield strength YS, tensile strength TS, and elongation El.

(3) Impact Test

JIS No. 4 test piece was sampled from the length direction of each steel pipe, and the impact test was performed at -40°C to measure the Charpy absorbed energy vE_{-40} was measured.

(4) Corrosion Test

(1) Carbon dioxide gas corrosion test

The test piece (size: 3.0x25x50 mm) sampled from each steel pipe was pulled up after it was immersed in 25 mass % NaCl aqueous solution (solution temperature: 100°C) saturated with 3.0 MPa carbon dioxide in an autoclave for 7 days. After the corrosion product was removed from the test piece, presence/absence of corrosion holes was observed visually. After that, the weight of the test piece after the corrosion test was

measured and converted into the thickness reduction amount to derive the corrosion rate (mm/y).

[0030] The hole corrosion resistance was evaluated based on these results with the test piece having hole corrosion graded as 0 and the test piece having no hole corrosion graded as X [sic?]. Also, the corrosion rate: 0.127 mm/y was used as the threshold value. The carbon dioxide corrosion resistance was evaluating by grading the test piece with a corrosion rate equal to or higher than the threshold value as X and the test piece with a corrosion rate lower than the threshold value as 0.

(2) SSC test

The test piece (size: 6.4 mm ϕ) sampled from each steel pipe was used to carry out the constant load test according to NACE-TM 0177 method A to evaluate the SSC resistance. The test solution was prepared by adding CH₃COONa into 5 mass % NaCl + 0.5 mass %CH₃COOH aqueous solution to adjust the pH to 3.5. Also, the test was carried out when a gas mixture of 1 % H₂S + 99 % CO₂ was blown into the test solution. The load stress was 90 %YS, and the test time was 720 h. The yield stress (654 MPa) of the lower limit of the X80 specification was used for YS.

[0031] Two steel pipes of the same kind (length 0.5 m) were prepared, and the ends (V-groove processing) were abutted against each other. GMAW welding method was used to perform circumferential welding to form steel pipe joint.

Presence/absence of weld cracking was observed in the formed steel pipe joint part. The welding condition of the circumferential welding was the GMAW welding method with heating: 19.5 kJ/cm (voltage: 14.5 V, current: 157 A, welding rate: 7.0 cm/min). No preheating or post-heating was performed.

[0032] The weld cracking was evaluated by observing the welded cross section. The weld cracking property was evaluated by grading the test piece as 0 if no weld cracking occurred and as X if weld cracking occurred. Also, a Charpy impact test piece (JIS No. 4 test piece) was sampled from the heat-affected zone (HAZ) of the steel pipe joint part to derive the Charpy absorbed energy vE-40 at test temperature of -40°C.

[0033]

The test results are shown in Table 2.

[0034]

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| 鋼 No | 化 学 成 分 (質量%) | | | | | | | | | | | |
|---------|---------------|------|------|------|-------|------|------|------|------|-------|-----------------------------|-------|
| | C | Si | Mn | P | S | Cr | Ni | Mo | Al | N | Ti, Nb, Zr, Ta, V | Cu |
| A | 0.012 | 0.31 | 1.35 | 0.02 | 0.001 | 12.6 | 5.12 | 1.86 | 0.02 | 0.014 | — | — |
| B | 0.011 | 0.51 | 1.08 | 0.02 | 0.001 | 12.4 | 4.86 | 1.67 | 0.02 | 0.021 | Nb:0.024, V:0.033 | — |
| C | 0.009 | 0.31 | 1.28 | 0.02 | 0.001 | 11.8 | 3.19 | 1.99 | 0.02 | 0.014 | Ti:0.047 | — |
| D | 0.008 | 0.22 | 1.45 | 0.01 | 0.001 | 12.1 | 4.31 | 1.56 | 0.02 | 0.003 | Zr:0.018, V:0.016, Ta:0.011 | — |
| E | 0.010 | 0.21 | 1.04 | 0.02 | 0.002 | 12.2 | 4.59 | 1.86 | 0.01 | 0.012 | — | — |
| F | 0.011 | 0.29 | 1.39 | 0.01 | 0.001 | 11.9 | 5.33 | 2.35 | 0.02 | 0.018 | — | 0.031 |
| G | 0.010 | 0.25 | 1.55 | 0.01 | 0.001 | 12.8 | 4.55 | 1.78 | 0.02 | 0.003 | V:0.027 | 0.002 |
| H | 0.012 | 0.32 | 1.31 | 0.02 | 0.001 | 11.8 | 3.74 | 0.01 | 0.02 | 0.019 | — | — |
| I | 0.011 | 0.33 | 1.38 | 0.02 | 0.002 | 9.8 | 4.23 | 2.06 | 0.02 | 0.023 | Nb:0.011, V:0.047 | — |
| J | 0.014 | 0.28 | 1.26 | 0.01 | 0.001 | 12.8 | 2.51 | 1.39 | 0.02 | 0.009 | Ti:0.025 | — |
| K | 0.021 | 0.31 | 1.28 | 0.02 | 0.002 | 12.1 | 3.92 | 1.59 | 0.02 | 0.012 | — | — |
| L | 0.012 | 0.29 | 1.06 | 0.01 | 0.002 | 12.0 | 0.14 | 1.41 | 0.02 | 0.009 | — | — |
| M | 0.009 | 0.30 | 1.19 | 0.01 | 0.001 | 12.3 | 4.35 | 1.66 | 0.02 | 0.075 | — | — |
| N | 0.014 | 0.24 | 1.24 | 0.01 | 0.002 | 11.6 | 4.66 | 1.75 | 0.02 | 0.015 | Ti:0.039 | — |

Table 1

[Column headings, left to right]:

Steel No.

Chemical components (mass %)

[0035]

Table 2

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12 3 10

| 鋼種 No. | 鋼種 No. | 熱処理条件 | | 鋼管規格 | | 鋼管性能 | | | | | | 備考 | |
|-----------|-----------|-----------|-----------|----------|----------|-----------------|----------------|------------------|--------------|--------------|-------------|-----|---------------|
| | | 加熱温度 ℃ | 冷却速度 ℃ | 規格 mm | 規格 mm | 母材 強度 MPa | 母材 延伸率 % | 母材 断面収縮率 % | 鋼管の強度 MPa | 鋼管性能 | | | |
| | | | | | | | | | | 鋼管の強度 MPa | 鋼管の延伸率 % | | 鋼管の断面収縮率 % |
| | | | | | | | | | | | | | |
| 1 | A | 830 | 820 | 78.3 | 24.2 | 808 | 219 | 21 | 0.082 | ○ | ○ | ○ | 本規格例 |
| 2 | A | 850 | 820 | 78.3 | 25.5 | 831 | 248 | 22 | 0.080 | ○ | ○ | ○ | 本規格例 |
| 3 | A | 810 | 840 | 84.8 | 14.3 | 184 | 216 | 23 | 0.084 | ○ | ○ | ○ | 本規格例 |
| 4 | A | 810 | 810 | 80.8 | 2.2 | 186 | 197 | 24 | 0.085 | ○ | ○ | × | 比較例 |
| 5 | A | 800 | 87.4 | 2.7 | 138 | 136 | 25 | 0.083 | ○ | ○ | × | 比較例 | |
| 6 | A | 810 | 820 | 81.3 | 17.9 | 178 | 260 | 26 | 0.085 | ○ | ○ | ○ | 本規格例 |
| 7 | A | 820 | 850 | 76.3 | 53.1 | 235 | 249 | 27 | 0.084 | ○ | ○ | ○ | 本規格例 |
| 8 | A | 810 | 810 | 85.4 | 18.8 | 183 | 238 | 28 | 0.083 | ○ | ○ | ○ | 本規格例 |
| 9 | A | 810 | 810 | 88.2 | 5.2 | 140 | 185 | 29 | 0.084 | ○ | ○ | × | 比較例 |
| 10 | C | 810 | 810 | 88.7 | 6.3 | 189 | 188 | 30 | 0.077 | ○ | ○ | ○ | 本規格例 |
| 11 | D | 810 | 810 | 88.8 | 12.9 | 219 | 258 | 31 | 0.042 | ○ | ○ | ○ | 本規格例 |
| 12 | E | 810 | 820 | 82.5 | 9.7 | 147 | 204 | 32 | 0.037 | ○ | ○ | ○ | 本規格例 |
| 13 | F | 810 | 810 | 92.8 | 16.3 | 202 | 238 | 33 | 0.044 | ○ | ○ | ○ | 本規格例 |
| 14 | G | 810 | 810 | 84.6 | 14.7 | 208 | 249 | 34 | 0.052 | ○ | ○ | ○ | 本規格例 |
| 15 | H | 810 | 830 | 91.7 | 9.6 | 189 | 265 | 35 | 0.091 | ○ | × | × | 比較例 |
| 16 | I | 810 | 810 | 85.5 | 13.8 | 189 | 188 | 36 | 0.034 | × | × | × | 比較例 |
| 17 | J | 810 | 810 | 86.0 | 3.1 | 168 | 164 | 37 | 0.057 | ○ | ○ | × | 比較例 |
| 18 | K | 810 | 810 | 82.0 | 4.9 | 25 | 27 | 38 | 0.085 | ○ | × | × | 比較例 |
| 19 | L | 830 | 810 | 88.2 | 0.5 | 26 | 28 | 39 | 0.147 | × | × | × | 比較例 |
| 20 | M | 810 | 830 | 88.3 | 0.3 | 31 | 23 | 40 | 0.184 | × | × | × | 比較例 |
| 21 | N | 810 | 810 | 88.3 | 12.5 | 29 | 4 | 41 | 0.074 | ○ | ○ | × | 比較例 |
| 22 | O | 810 | 810 | 88.1 | 17.9 | 179 | 371 | 42 | 0.066 | ○ | ○ | ○ | 本規格例 |

23 24

25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

- 1 Steep pipe No.
- 2 Steel No.
- 2 Heat treatment condition
- 4 Quenching
- 5 Tempering
- 6 Temperature
- 7 Texture of the steel pipe
- 8 Type
- 9 Area %
- 10 Characteristics of the steel pipe
- 11 Tenacity of the welded part
- 12 Weld cracking property
- 13 Base material

14 Presence/absence of cracks

15 Corrosion resistance

16 Corrosion rate

17 Evaluate

18 Presence of hole corrosion

19 SSC resistance

Presence/absence of cracks

20 Note

21 No

22 Yes

23 Example of the present invention

24 Comparative Example

*) M: Martensite, F: Ferrite, B: Bainite, γ : Austenite

[0036] All of the examples of the present invention have excellent strength and tenacity and can be circumferentially welded without performing pre- or post-heat treatment. The examples of the present invention also have excellent weld cracking resistance and excellent tenacity in the heat-affected zone, excellent hole corrosion resistance and full surface corrosion resistance in corrosive environment containing carbon dioxide, and excellent SSC resistance in corrosive environment containing hydrogen sulfide. On the other hand, one or more of the aforementioned characteristics deteriorate in the comparative examples outside the scope of the present invention.

[0037]

[Effect of the Invention] According to the present invention, high Cr martensite stainless steel pipe for line pipe, which has excellent corrosion resistance in corrosive environment containing carbon dioxide or hydrogen sulfide and can be circumferentially welded without pre- or post-heat treatment, can be easily manufactured at low cost to achieve significant effects in the industrial field. Also, pipelines used for transporting petroleum/natural gas can be manufactured at low cost according to the present invention.